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Guest Editorial for the Special Issue on Type-2 Fuzzy-Model-Based Control and its Applications

This Special Issue is dedicated to the memory of Professor Robert John, one of the pioneers of type-2 fuzzy sets and systems, who passed away during the preparation of this Issue.

TYPE-2 fuzzy sets were proposed by Prof. Lotfi A. Zadeh in 1975 as a way to handle membership function uncertainties. Although a small number of papers were published about type-2 fuzzy sets during the following 20 years, it was not until Prof. Jerry Mendel, his students, and other colleagues he collaborated with, including Prof. Robert John (to whom this Special Issue is dedicated), worked on type-2 fuzzy systems (a.k.a., fuzzy logic systems) that the field of type-2 fuzzy sets and systems began to blossom (e.g., as summarized in [1] and [2]). Because type-1 fuzzy logic control was already one of the most important and widely studied applications for type-1 fuzzy sets, it was very natural for type-2 fuzzy logic control to emerge [3]. As is well known, control systems must often be designed to perform well in the face of uncertainties, including external but unmeasurable disturbances that act upon the plant, changing plant parameters due to aging or other effects, incomplete knowledge about parameter values, and specific control mechanisms, such as sampling, event-triggering, etc. Type-2 fuzzy sets have the potential to better handle such uncertainties because they lead to controllers that provide a greater sculpting capability of the state space (i.e., to more non-linearity, adaptivity and variability of the controller structure) than do type-1 fuzzy logic controllers. This greater sculpting is provided by more design degrees of freedom that occur in type-2 fuzzy set models. Just as there can be different kinds of type-1 fuzzy logic controllers, there can also be different kinds of type-2 fuzzy logic controllers. The book [4], which is co-edited by five scholars, is an excellent entry into type-2 fuzzy logic controllers; however, each of its four type-2 fuzzy logic controller chapters focuses on the contributions made by its co-author (and students). This Special Issue, which focuses on type-2 model-based control, adds to what is in [4] and demonstrates the broadening of the type-2 fuzzy logic controller field.

During the past three decades, type-1 fuzzy-model-based (FMB) control strategies have been shown to effectively address the nonlinearity in the control systems. Benefiting from the pioneering concept of parallel distributed compensation (PDC) proposed by Prof. Kazuo Tanaka and his colleagues including Prof. Hua O. Wang [5], the stability analysis of type-1 FMB control systems can now be conducted systematically. The PDC concept lays down the foundation driving the development of type-1 FMB control research. As shown in [5], a wide range of research topics within the type-1 FMB control framework have been investigated through strict mathematical approaches, e.g., the fuzzy observer design, robust fuzzy control, optimal fuzzy control, etc. Under the type-1 FMB control framework, Dr. Hak-Keung Lam has taken it to another level that by introducing 1) Imperfect Premise Matching (IPM) Concept that advocates the fuzzy controller can have its own set of premise membership functions and 2) Membership-Function-Dependent (MFD) Analysis that initiates the use of membership-function information in stability analysis and control design [6]. The monograph [6] summarized in-depth many results in terms of the categories of the FMB control systems, types of Lyapunov functions, types of analysis techniques, and amount of membership-function information and its extraction. In general, type-1 FMB control strategies are very powerful for nonlinear systems. Nevertheless, type-1 fuzzy sets lack the capability of directly handling (modeling) the previously mentioned uncertainties.

A type-2 FMB control framework can be established by adopting type-2 fuzzy sets into type-1 FMB designs. Doing this, the resulting type-2 FMB controller inherits the merits of both type-2 fuzzy sets and the FMB control strategy, and has the unique advantage of directly handling both nonlinearity and uncertainty. However, the big challenges are 1) a type-2 fuzzy model and its modeling method, and type-2 fuzzy controller under the FMB control framework is lacking; and 2) new analysis techniques have to be developed because PDC-based analysis cannot be applied when the premise membership functions are of type-2. Since the first successful attempt was made in 2008 [7] to address these issues, the interval type-2 (IT2) FMB control system, its stability analysis, and control design have gradually been recognized by the fuzzy control community. The IPM concept and MFD analysis were also investigated through the IT2 fuzzy sets in [8], which are significant concept and techniques support the stability analysis and control design. Besides the parameter uncertainty, the type-2 fuzzy sets have also demonstrated their potential to deal with the intrinsic uncertainty caused by specific control mechanisms, such as the sample-data control mechanism, event-triggered control mechanism, etc.

After the two special issues on type-2 fuzzy sets and systems proposed by IEEE TRANSACTIONS ON FUZZY SYSTEMS in 2007 and 2013, the importance and merit of type-2 fuzzy sets have gained even more attention. Since the significance of type-2 FMB control and related applications have drawn the attention of many researchers, we made a call for another type-2 special issue about this topic. In total, 31 submissions were received and 11 submissions of those were accepted upon the careful evaluations of the reviewers, guest editors, and the Editor-in-Chief.

The paper entitled "Stability Analysis for Interval Type-

2 Fuzzy Systems by Applying Homogenous Polynomially Membership Functions Dependent Matrices and Switching Technique," by Wang et al., uses the homogenous polynomially membership functions dependent matrices for the IT2 fuzzy systems to reduce the conservativeness in the stability conditions. The simulations verify that the method in this paper is less conservative than the existing ones reported in the literature.

The paper entitled "Fault Estimation for Mode-Dependent IT2 Fuzzy Systems with Quantized Output Signals," by Sakthivel et al., presents a fault estimation for mode-dependent IT2 fuzzy systems with quantized output measurements. By offering three illustrative examples, in which two of them are practical models, namely, the tunnel diode circuit system and Rössler system, the availability and feasibility of the proposed design method are explained.

The paper entitled "Towards Systematic Design of General Type-2 Fuzzy Logic Controllers: Analysis, Interpretation and Tuning," by Sakalli et al., provides a new perspective on how the deployment of General Type-2 (GT2) fuzzy sets affects the mapping of a class of fuzzy logic controllers. Also, the systematic design approach for GT2-FLCs is presented. In the paper, the analyses, interpretations, and design methods are validated with experimental results conducted on a drone.

The paper entitled "Security Sliding Mode Control of Interval Type-2 Fuzzy Systems Subject to Cyber Attacks: The Stochastic Communication Protocol Case," by Zhang et al., addresses the security control problem of a class of IT2 fuzzy systems via the sliding mode control strategy. In the paper, sufficient conditions are derived so that the resultant closed-loop interval type-2 fuzzy system is stochastically stable and, at the same time, the state trajectories can be forced into a small domain around the prescribed sliding surface. The proposed control design approach is verified by two examples.

The paper entitled "Design on Type-2 Fuzzy-based Distributed Supervisory Control with Backlash-like Hysteresis," by Shen et al., investigates the distributed synchronization control subject to the unknown backlash-like hysteresis by using the smooth function approximation capability of type-2 fuzzy logic systems. In the paper, it is guaranteed that the resulting closed-loop signals including system states belong to the corresponding compact sets. The adaptive compensation terms of the optimal approximation errors are adopted in the proposed method. Simulation results demonstrate the effectiveness of the proposed new design method.

The paper entitled "Asynchronous Event-Triggered Control for Networked Interval Type-2 Fuzzy Systems against DoS Attacks," by Li et al., investigates the asynchronous adaptive event-triggered control problem for networked IT2 fuzzy systems subject to nonperiodic denial-of-service (DoS) attacks. Two resilient adaptive event triggered mechanisms are applied independently to both sensor and controller output while resisting nonperiodic DoS attacks. Mismatched membership functions are considered between the dynamic output feedback controller and IT2 fuzzy model, and a slack matrix is introduced to relax the stability conditions. The effectiveness of the developed control approach is illustrated by two examples.

The paper entitled "A Novel Hammerstein Model for Nonlinear Networked Systems based on an Interval Type-2 Fuzzy Takagi-Sugeno-Kang System," by Khalifa et al., proposes a novel Hammerstein structure for nonlinear networked systems based on an IT2 Takagi-Sugeno-Kang fuzzy system. The structure of the nonlinear subsystem is learned online based on the type-2 fuzzy clustering and the update algorithms are utilized to assure the model stability and the parameter fast convergence. The simulation results show a higher performance for the proposed model than that of compared models.

The paper entitled "Efficient Model Predictive Control for Networked Interval Type-2 T-S Fuzzy System with Stochastic Communication Protocol," by Dong et al., investigates the efficient model predictive control problem of a class of nonlinear systems in the framework of IT2 T-S fuzzy systems. In the paper, the balance among the computational burden, the control performance, and the initial feasible region has been considered. The effectiveness of the proposed method is verified through simulation examples.

The paper entitled "Fault Detection Filtering Design for Discrete-Time Interval Type-2 T-S Fuzzy Systems in Finite Frequency Domain," by Wang et al., focuses on the problem of fault detection filtering design for discrete-time IT2 T-S fuzzy systems in the finite frequency domain. By exploiting the information of footprint of uncertainty (FOU) and lower and upper membership functions of the fuzzy system, a novel MFD finite frequency fault detection filtering design approach has been proposed and then applied to the fault detection. The effectiveness of the proposed fault detection methods has been verified through simulation studies.

The paper entitled "Aperiodic Sampled-Data-Based Control for Interval Type-2 Fuzzy Systems via Refined Adaptive Event-Triggered Communication Scheme," by Li et al., devotes to event-triggered stabilization for a class of IT2 fuzzy systems with aperiodic sampling. Benefiting from the merits of the proposed research, the conservatism is significantly reduced for obtaining upper bound for stable sampling interval and achieves obvious superiority over the existing methods for saving communication resource while maintaining the control performance of the system.

The paper entitled "Affine Transformed IT2 Fuzzy Event-Triggered Control under Deception Attacks," by Han et al., investigates the stabilization of type-2 fuzzy system in the presence of cyberattacks. In this paper, affine membership functions are considered in the controller design. Also, robust adaptive event-triggered control is proposed to avoid unwanted triggering events. The experimental results demonstrate the importance of the proposed approach in terms of state convergence, robustness, and avoiding unwanted triggering events.

To conclude, a wide range of related topics have been collected for the special issue. Especially some of the hot research topics from the networked control field like the sampled-data control design, event-triggered control design, the dynamic output control design against cyberattacks, such as DoS, deception attacks, etc. From those research outcomes, it demonstrates that type-2 control strategies are effective to address the uncertainties in the control systems. Fault estimation and detection are also hot research topics to be discussed through the IT2 control design. Besides, there are

IT2 FMB control designs combined with other types of control frameworks are reported, such as the model predictive control and sliding mode control. The stability analysis of the hybrid control systems is conducted through the MFD approach, which shows the potential of implementing type-2 control design with other control design frameworks. In addition, the design of the general type-2 FLC is presented in this special issue.

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